VOLUME 78

SEPARATE No. D-115

PROCEEDINGS

AMERICAN SOCIETY OF CIVIL ENGINEERS

NOVEMBER, 1952

AMERICAN SOCIETY OF CIVIL ENGINEERS FOUNDED 1852

DISCUSSION OF LAKE MICHIGAN EROSION STUDIES

(Published in February, 1952)

By Thomas B. Casey, Charles E. Lee, and John R. Hardin and William H. Booth, Jr.

WATERWAYS DIVISION

Headquarters of the Society
33 W. 39th St.
New York 18, N.Y.

PRICE $0.50 PER COPY

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Published at Prince and Lemon Streets, Lancaster, Pa., by the American Society of Civil Engineers. Editorial and General Offices at 33 West Thirty-ninth Street, New York 18, N. Y. Reprints from this publication may be made on condition that the full title of paper, name of author, page reference, and date of publication by the Society are given.

DISCUSSION

Thomas B. Casey,[3] M. ASCE.—Three of the points developed in the paper are believed worthy of further mention, both with respect to the basic and fundamental importance of the facts stated and with regard to studies currently in progress on the problems involved. These three items, listed in reverse order from that in the paper for convenience in discussion, are as follows:

> *a.* "From the description of the protective works, it is apparent that the problems of arresting shore line erosion involve many geological and engineering considerations." (See under the heading, "Summary.")
>
> *b.* "If groins were constructed along the entire reach [that is, the Northern Lake Plain Section], the littoral drift would be absorbed or discontinued and might result in erosion to the south. The number of groins constructed per year should be governed by the amount of littoral drift traveling along the section under consideration." (See under the heading, "Recommended Improvements: 1. Northern Plain Section.")
>
> *c.* "The main physical forces that are responsible for this erosion are wind, wave, and current action." (See under the heading, "Introduction.")

Even the most cursory and superficial examination of the erosion problem will convince one of the validity of the statement made in item *a.* This fact is even more apparent when one delves more deeply into the problem and begins to comprehend the number, type, and extent of the factors present, and the complex and often unpredictable interrelationships involved, together with the fact that the primary erosive agents are forces of nature beyond the control of man. The authors state (under the heading, "Factors Affecting Erosion: Protective Structures") "***in the past, local judgment has generally determined the method or methods to be used in improving and stabilizing the shore line." There is no question but that this has been the case and that this is largely the reason for the further conclusion, "Some [methods] have been effective, and others have been useless." These efforts cannot be strongly condemned, however, because an adequate knowledge of the nature and extent of the engineering and geological problems involved was not available, and necessity dictated that design proceed on the basis of available information. Not only in the past has this been the case but even at the present time the knowledge of the fundamental characteristics of the basic elements involved in the erosion problem is wholly deficient. Therefore present-day efforts at shore protection on Lake Michigan are still based largely on judgment, and although there are undoubtedly many factors and relationships analogous to all beach erosion problems, the solution of each requires separate study and evaluation. Thus, the problems on Lake Michigan cannot be solved simply by analogy with problems on the Pacific coast; they require a study and knowledge of the several factors as they exist on Lake

Note.—This paper by John R. Hardin and William H. Booth, Jr., was published in February, 1952, as *Proceedings-Separate No. 115.* The numbering of footnotes in this separate is a continuation of the consecutive numbering used in the original paper.

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Michigan. Thus it is that serious deficiencies in basic data do exist and that, until these have been corrected, efforts at protection must continue on a basis of individual ingenuity and judgment.

The matters presented by the authors under item *b* immediately raise questions about which deficiencies in basic information exist. Disregarding, for the moment, the physical forces that the groin system must withstand, and neglecting entirely the important and interesting legal questions inherent in the recommendation that the number of groins constructed per year should be governed by the amount of littoral drift traveling along the reach under consideration, one is concerned necessarily, with a number of questions relative to the basic characteristics of the littoral drift itself as a prerequisite to the design of the groin system. In other words, the successful solution of a beach erosion problem, like any other engineering problem, is predicated on the definition of the physical conditions causing the problem. In so far as shore erosion is concerned, and with particular reference to the littoral drift, Martin A. Mason,[4] M. ASCE, has propounded three questions which, if answered, serve to define the causative physical conditions: What are the sources and character of the beach material? What are the rates of supply and loss of material to and from the problem area? What is the manner of movement of material from the source to the beach and from the beach to other areas?

Prior to the surveys and studies conducted by the Chicago District, Corps of Engineers (in the course of the preparation of the cooperative beach erosion report on the Illinois shore of Lake Michigan), virtually nothing had been done in that state toward any comprehensive and integrated study of these several factors. It is apparent that one such survey of these complex and erratic factors is inadequate to serve as a basis for well-founded conclusions relative thereto, and that studies must be conducted systematically over a period of years before definite trends and patterns can be established.

In recognition of the need for such a coordinated and systematic study, the State of Illinois initiated a program in 1950 which has as its primary objective the more precise definition of the causative conditions as set forth in the foregoing three questions. These studies, as presently programed, entail the following features with respect to the littoral drift:

1. Periodic soundings on selected ranges;
2. The taking of bottom surface samples on the sounding ranges at frequent intervals;
3. Cross sectioning and sampling of the beaches and bluffs at selected locations;
4. Measurement of shore erosion or accretion by actual field survey and study of aerial photographs;
5. Detailed study of the effect of various storms on the trap efficiency of selected existing groins of various types; and
6. Laboratory analysis of samples for grain size and heavy mineral, magnetic mineral, and carbonate content.

[4] "Method of Solution of Shore Problems," by Martin A. Mason, *Bulletin*, Beach Erosion Board, Washington, D. C., January, 1948.

These procedures, together with others that may be developed in the course of the studies, must be applied over a period of time sufficient to cover a variety of conditions of lake stage—storm direction, duration, and intensities; and seasonal changes to provide a clear picture of the characteristics of the littoral drift along these shores. This study will then enable the engineer to determine the most feasible and economical method of providing remedial measures and to predict with a reasonable degree of accuracy the adequacy of the measures toward achieving the desired protection and their effect on other reaches of shore.

Of the three major physical forces stated in item *c*, neither wind nor currents, by themselves, are considered to have any major status as erosive agents on these shores. Beyond doubt, the primary erosive agent is wind-generated waves which, in deep water, generally vary both in magnitude and direction with the intensity and direction of the generating wind. Here again, the engineer reponsible for the design of protective measures is confronted with a deficiency in basic knowledge. Waves are not only the principal erosive agent but also are responsible for the transport of beach material in that littoral current is primarily the long-shore component of the wave impinging upon the shore. In addition, the major forces which the protective works must be capable of withstanding structually are wave forces.

The effectiveness of wave attack in shore erosion varies not only with the magnitude and direction of the deep-water waves but with the configuration of the shallow near-shore bottom (refraction effect), the stage of the lake, the topography and character of the material of which the shore is composed, and the character and extent of existing shore protection works. Of these several factors, all except the first are generally susceptible of evaluation by ordinary and well-known methods of field survey, and observation and data thereon can be had without undue difficulty. The real deficiency exists in accurate information on the remaining and most important factor—that is, the magnitude and direction of the deep-water waves.

In order to overcome this basic deficiency, the current program of beach erosion studies includes the observation of deep-water wave characteristics, lake stage, and wind direction, duration, and intensity. Each of these factors possesses points of major interest, and, indeed, lake stage is a favorite topic of conversation along the shores of the Great Lakes at the present time (1952) due to the generally prevailing high-stage cycle. It is considered expedient here, however, to mention only a few points of interest on these matters.

Observations of lake stages are being made (1952) at the Wilson Avenue Waterworks Intake Crib of the City of Chicago, located some 3 miles offshore, and at the Waukegan Waterworks at Waukegan Harbor for sounding and sampling operations and to study lake level changes at these locations in comparison with those at other gaging points. These stage changes include not only the normal fluctuation of the average elevation of the lake, but those shorter fluctuations caused by wind setup and changes in barometric pressure—all of which have an important bearing on the effectiveness of wave attack on the shores.

Continuous observations of wind direction, intensity, and duration are made at the same sites. These observations are particularly important because wind is the generating agent for the waves and in that sense may be the real cause of shore erosion on Lake Michigan. Furthermore, observation of wind direction is important because no satisfactory method for determining wave direction directly has yet been derived, and it is necessary to assume that deep-water wave direction varies generally with wind direction. It is also of interest to note that analysis of the data thus far obtained substantiates the findings reported by the late John R. Freeman[5] (Past-President, ASCE) in 1926 that wind velocities observed at points out in the lake are often materially greater than those observed at United States Weather Bureau stations on shore. Thus, records from shore stations cannot be relied upon to give a true picture of storm intensities on the lakes.

TABLE 1.—Storm of November 5 to 8, 1951, Lake Michigan at Wilson Avenue Intake Crib, Chicago Ill.,

Date (November, 1951)	Central Standard Time[a]	Lake stage (mean tide at New York, N. Y.)	Wind		Waves		
			Direction[b]	Velocity[c]	Time[d] (sec)	Height, in Feet	
						Average[e]	Maximum[f]
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
5	11:30 p.m.	581.05	118	16	...	...	...
6	11:25 a.m.	581.62	87	33	5.81	5.02	7.75
6	11:26 p.m.	582.10	50	34	7.42	5.58	9.35
7	11:26 a.m.	582.35	353	44	9.17	6.05	8.57
7	11:27 p.m.	582.05	322	20	8.84	4.19	6.00
8	11:27 a.m.	581.35	275	18	7.14	1.68	2.99

[a] Period of analysis generally extends 15 min beyond indicated time. [b] Wind direction expressed as azimuth measured clockwise from north. [c] Wind velocity in miles per hour. [d] Average period of well-defined series of highest waves recorded. [e] Average height of ⅓ highest waves observed during period of analysis. [f] Highest single wave observed.

In order to obtain data on deep-water wave characteristics, a Mark IX Wave Recorder was established at the Wilson Avenue Waterworks Intake Crib in 1951 and a similar unit is scheduled for installation off Waukegan Harbor in 1952. Data from these gages, which are generally operative only for the period from May to November of each year because of the danger of losing instruments from ice action during the winter months, will provide reliable information as to the period and height of deep-water waves, from which other characteristics may be deduced from derived relationships.

In condensed form, Table 1 contains data taken from recording instruments at the Wilson Avenue Waterworks Intake Crib for the storm of November 5 to 8, 1951, and will serve to give some indication as to the type and extent of data being obtained.

In conclusion, the statement of the authors that "***the problems of arresting shore line erosion involve many geological and engineering considera-

[5] "Regulation of the Great Lakes and Effect of Diversion," by John R. Freeman, Chicago San. Dist., Chicago, Ill., October, 1926.

tions" is here repeated for the sake of emphasis. Most shore erosion control works are admittedly costly, and experience has shown that the construction of such works without a knowledge of the characteristics of the factors involved often not only fails to achieve the desired purpose, but indeed may prove to aggravate conditions in the problem area and elsewhere—all with a consequent heavy financial loss to the owner. Few will deny that adequate knowledge of these factors is lacking and that the studies necessary to define them, even over a relatively limited shore line such as that of Illinois, are far beyond the scope of the engineer engaged in designing protective measures at a particular site. The task must then devolve upon an organization whose scope extends beyond the limitations of the individual or the political subdivision.

The report upon which the paper is based constituted the first step along those lines in Illinois.

CHARLES E. LEE,[6] A.M. ASCE.—The paper under discussion deals with the Lake Michigan shore line and the attending remedies for erosion, considering average lake levels. The writer will discuss, in general terms, the high lake levels, and the feasibility of the proposed plans for providing adequate protection during the rare-frequency, long-term fluctuation of the lake level—basing his discussion on the Fort Sheridan (Illinois) observations.

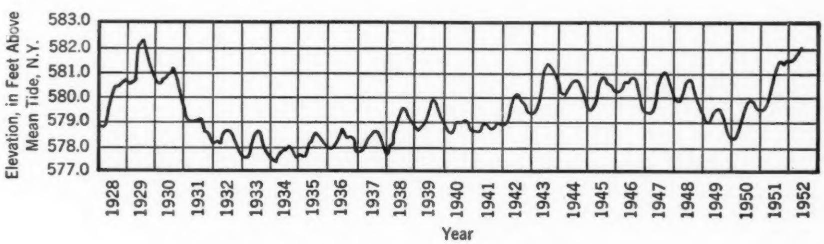

FIG. 5.—MEAN ELEVATION OF LAKE MICHIGAN

The timeliness of the paper was shown expressly by a survey of damage to the Lake Michigan shore line occurring between the spring of 1951 and the spring of 1952. There was a higher rate of damage during that time than was ever recorded before. This damage could be related directly to the increase in development of the shore line properties and to the existing high level of the Great Lakes which caused inundation of greater area and greater depths of water at structures and at the toe of the bluffs. This high lake level, of course, permitted waves to propagate farther inland and caused waves of greater height to act on the structures and on the easily eroded bluffs.

The level of Lake Michigan fluctuates (in addition to temporary fluctuations such as seiches and lake setup) simultaneously in two separate patterns, one an annual variation and the other a long-term variation (see Fig. 5).

The annual variation of the lake level may be related to the seasonal pattern of the precipitational runoff. The low extreme of the curve is usually reached

[6] Hydr. Engr., Great Lakes Div., Corps of Engrs., Chicago, Ill.

during February, following the period of least runoff. As the thaw and spring rains begin, the curve rises until a peak is reached in the late summer months of July or August. The irregular long-term variation in lake level must also be related to precipitation, but experience shows that the long-term peak lake level does not occur during the same year as peak rainfall. The long-term variation was high in 1952, as might be expected, since analysis of records of precipitation on the Great Lakes drainage basin shows an ascending trend for the 16-year period, 1934–1950, and downward since that time, but still above average. The monthly mean elevation of Lake Michigan for July, 1952, was 582.66 ft above mean tide at New York, the highest monthly mean elevation attained since 1887. Gage readings for the early part of August, 1952, indicated a slight increase in stage. However, it was hoped that the seasonal crest would be reached during that month and that the stage would begin its normal seasonal decline. The highest one-month average level of record (from 1860 to 1952), was elevation 583.68, and occurred in June, 1886.

The damage that occurred in the spring of 1952 was intensified by the fact that the lake level did not descend, as is normal, during the winter of 1951-1952 (see Fig. 5). This phenomenon occurred only once previously during the 92-year period of record (fall to spring of 1928–1929). The high stages persisting through the seasonal period in which wind storms occur most frequently, and abetted by the resulting wind tides and seiches, permitted the high wind waves to proceed such a distance inland that extreme damage resulted.

As a result of the extremely high lake levels the Committee on Public Works of the United States House of Representatives authorized a review report having the scope of a preliminary examination, by a resolution adopted on March 26, 1952. The report was conducted under the direction of the division engineer, Great Lakes Division, Corps of Engineers, United States Department of the Army, and had as its purpose the determination of the property damage resulting from changes in levels of the Great Lakes and the feasibility of measures to prevent the recurrence of damages. The completed report, dated June 9, 1952 (hereinafter referred to as the "Corps of Engineers' report"), was submitted to the chief of engineers. The authorized scope of the report, with the attending limitations of funds and time, did not permit sufficient study to determine specific designs or make other than general recommendations. However, it was recommended that a comprehensive study of survey scope be made to determine:

1. The feasibility of a plan of regulation of the levels of the Great Lakes that will best serve the interests of all water uses, including the reduction of damages to shore properties, the use of the Great Lakes for navigation, and the use of the storage and outflows from the Great Lakes for power development; and

2. The advisability of adopting local-protection flood-control projects for areas along the shores of the Great Lakes and tributary streams that are subject to inundation as a result of fluctuations in the levels of the lakes, where such projects are found to be feasible and economically justified.

3. Also recommended were (*a*) a plan for coordinated shore protection by state and local governments, (*b*) shore protection measures by individual local property owners, and (*c*) the enactment of state and local legislation controlling shore line construction.

(*a*) A coordinated plan for the protection of shores and shore properties against the action of waves and currents was recommended for development by each of the states or political subdivisions thereof for their shores fronting the Great Lakes. Federal participation in these studies and the protection of publicly owned property would be governed by the provisions of Public Law No. 520, 71st Congress, approved July 3, 1930, and Public Law No. 727, 79th Congress, approved August 13, 1946.

(*b*) It was recommended that individual owners of properties bordering the Great Lakes provide such permanent or temporary protection for their properties from the action of waves and currents as is found by them to be warranted. Where feasible, the protection provided should be integrated into a comprehensive plan for a contained beach segment.

(*c*) States and political subdivisions of states adjoining the Great Lakes were advised to give consideration to the enactment of appropriate laws to control construction in areas subject to wave attack or shore line recession, and in the flood plain of the Great Lakes.

The Corps of Engineers' report also disclosed that damages in the sum of $61,252,900 occurred along the 5,479 miles of United States shore line (including islands) of the Great Lakes, of which $49,970,750 could be related directly to wave action. Of this total, $11,288,000 worth of damage occurred along the 108 miles of shore line in the State of Illinois, of which $11,097,700 may be related directly to wave action.

In accordance with the division engineer's recommendation, a survey report was authorized and prepared.

Preliminary estimates of the increase in shore line recession during 1951, as compared with the average rates given by the author (see under the heading, "Shore Line Changes"), have been made for (1) the Northern Lake Plain Section, (2) the Lake Border Moraine Section, and (3) the Southern Lake Plain and Artificial Fill Sections.

(1) *Northern Lake Plain Section.*—An increase of 500% is estimated for the vicinity of Winthrop Harbor and Illinois Beach State Park. The average increase throughout the entire section is about 300%.

(2) *Lake Border Moraine Section.*—An increase of more than 200% is estimated over the entire section—with a much larger rate in parts of Wilmette and Fort Sheridan.

(3) *Southern Lake Plain and Artificial Fill Sections.*—It is estimated that the recession rate increased approximately 75% during 1951.

Because of this increased erosion and other damage, some construction was required to prevent complete destruction of property or irreparable damage. The construction, in general, was of protective walls, groins, or combinations of both. The writer knows of no detailed data concerning the effec-

tiveness of the new construction, except for the case that follows. In April, 1951, a contract was let for the construction of ten groins on the United States Army Reservation of Fort Sheridan, in the Lake Border Moraine Section (a total of twenty one were recommended for the entire reservation). Five of these groins, spaced from 300 ft to 400 ft apart, were constructed during the period of May through August, 1951, according to the design described by the author (see under the heading, "Recommended Improvements"). The remaining five groins covered by the aforementioned contract were scheduled for construction during the summer and fall of 1952. However, during a summer storm the downdrift end groin was outflanked and the impounded beach was lost. Because of this loss and because of construction difficulties at high lake stages, construction of the five additional groins, to their entire length, did not appear feasible. It was decided that the inner portions of the groins (the length that could be accomplished by land plant) would be constructed during the fall of 1952, and the remainder in the spring of 1953. From August to December, 1951, a series of monthly soundings were taken to determine the effectiveness of the groins in impounding the beach material that traveled along the shore (ice prevented sounding during the winter months). There were two lines of soundings for each groin—one immediately updrift of the groin, and one midway between the groins. The lines extended from the toe of the bluff to the 6-ft depth contour (referred to low water datum for Lake Michigan, which is about 4.2 ft below the July, 1952, lake level). The surveys indicated that a slight accretion had occurred between the shore line and the 6-ft depth contour, opposite the five constructed groins. The accretion shoreward of the shore line was negligible, except at the two most northerly (updrift) groins.

Surveys of the area made in April and May, 1952, after the ice had melted, revealed further accretion at these five groins. Specifically, it was indicated that there was some loss of material updrift of the first groin (numbering consecutively from north to south or updrift to downdrift), but that an extensive gain had occurred in the area between that and the penultimate groin; some loss was revealed between the penultimate and end groins; and erosion had taken place downdrift of the end groin. Therefore, it may be concluded that the three updrift groins were filled to the extent that an appreciable volume of material was flowing around the outer ends of, and over, the groins, but that a condition of slight deprivation existed below the fourth groin. A preliminary estimate of quantities showed a total gain of more than 12,000 cu yd during the period from December, 1951, to May, 1952. The rate of impoundment during this five-month period leads to the conclusion that reasonable protection would be afforded the area protected by the ten groins, and that a normal material balance would be restored in from 3 years to 4 years from the time of initial construction, if conditions remained favorable to accretive action.

The observed action of these groins over a short period was gratifying, as observations at other successful groins have revealed that a flattening of the offshore gradient preceded shore line and onshore accretion. Another example of the groins reacting according to design was the fact that at the updrift

groins the excess material passed over the groins, providing nourishment for the immediate downdrift side, which is usually most vulnerable to erosion. However, some erosion was noted in the vicinity of the most southerly groin, indicating a paucity of material in movement downdrift of the penultimate groin. In this regard, more consideration might be given to the desirability of further limiting the number of groins that should be constructed during any one season of average lake levels.

It is considered that the indications of successful action of the Fort Sheridan groins present considerable verification of the efficacy of the design presented by the author, for the Northern Lake Plain and the Lake Border Moraine sections. Proper limits should be placed on the amount of construction per year. It is believed that the groin design will provide adequate protection during periods of extremely high lake levels as well as during average lake levels.

John R. Hardin,[7] M. ASCE, and William H. Booth, Jr.,[8] A. M. ASCE.—Valuable additions to the subject of erosion have been provided by Messsrs Casey and Lee. It is gratifying to know that the State of Illinois has initiated a program for collecting basic data on the erosional forces along the Illinois shore line of Lake Michigan. It is hoped that other agencies will plan similar programs of this nature to be applied to the other Great Lakes. It is also gratifying to read, in Mr. Lee's discussion, that the groin system recently constructed at Fort Sheridan is performing as originally contemplated.

In the past, the protection of shore line against erosion has engaged far too little professional interest among engineers, in spite of the fact that the need for remedial works has become increasingly apparent. The study of shore erosion forces is in its infancy (1952); however, a considerable amount of detailed technical information is avilable describing the effect of wave action on beaches and concerning related problems. In spite of the advances made, much remains to be learned, and the existing (1952) scientific knowledge of shore erosion forces has not been satisfactorily disseminated through the engineering profession.

Littoral drift is an important consideration in providing protection along the coast. The quantity of drift can be evaluated by the volume of material trapped by shore structures, either natural or man-made, and from knowledge of the rate of depletion of sources of supply—for example, the erosion of bluffs or headlands. Each man-made structure extending into the water will have an effect on the erosional or dispositional forces, thereby causing changes in the immediate area. If several groins are constructed in a physiographic unit, the volume of impoundment might be sufficient to trap most or all of the littoral drift for several years, depending on the quantity of drift traveling in the area. It is agreed that studies over a period of years would indicate more clearly the trend in the volume of material traveling along the shore, but the emergency need for protection will not permit such investigations. The data pertaining to the Illinois shore line can be used to great advantage in planning the remedial measures.

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The writers would like to elaborate on the statement, made in their paper (see under the heading, "Introduction") and referred to by Mr. Casey, that "The main physical forces that are responsible for this erosion are wind, waves, and current action." Under the section entitled "Factors Affecting Erosion," the three forces are described. The dominant force is the wind-generated wave. The theory of the formation and growth of wind waves, as developed by H. U. Sverdrup and W. H. Munk of the Scripps Institution of Oceanography, University of California at La Jolla, takes into consideration wind speed, wind duration, and fetch and relates these variables to wave length, period, and velocity. Wave forecasts by the Sverdrup-Munk relationship have been shown by comparative observation to approximate natural conditions reasonably well. The offshore waves seldom travel in a direction perpendicular or parallel to the shore, but usually approach the shore at some intermediate angle. As the waves reach shoaling water having a depth of half the wave length, their characteristics (excepting the wave period) are modified. In particular, the velocity of advance is reduced and the wave length is shortened. This bottom effect causes a so-called refraction or bending of the wave in a direction such that the crest of the wave tends to conform to the bottom contours. The amount of these changes may be determined by the construction of "refraction diagrams." A refraction diagram may be considered to be a map showing the wave crests at a given time, or the successive positions of a particular wave crest as it moves shoreward. Crests several wave lengths apart are sufficient to show the bending of the waves. Such diagrams will indicate the direction of the alongshore component. Waves breaking at an angle to the beach produce a current that moves parallel to the beach; this is known as the littoral current. The effect of waves on a sand beach is especially pronounced at the breaker line, where large quantities of sand are thrown into suspension. The direction of wave approach causes the littoral current that carries suspended sand along the shore. Therefore, the main physical forces for the area under discussion are wind, waves, and currents.